Decadal Variability in the State of the Upper Tropical Pacific:
A Consequence of Scale Interaction?

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Outline

- What is the tropical Pacific decadal variability (TPDV) ?

- What are the climate consequences of TPDV?

- What causes TPDV?

  1. **Earlier Hypotheses**
  2. **Our Hypothesis**
  3. **Evidence for Our Hypothesis**
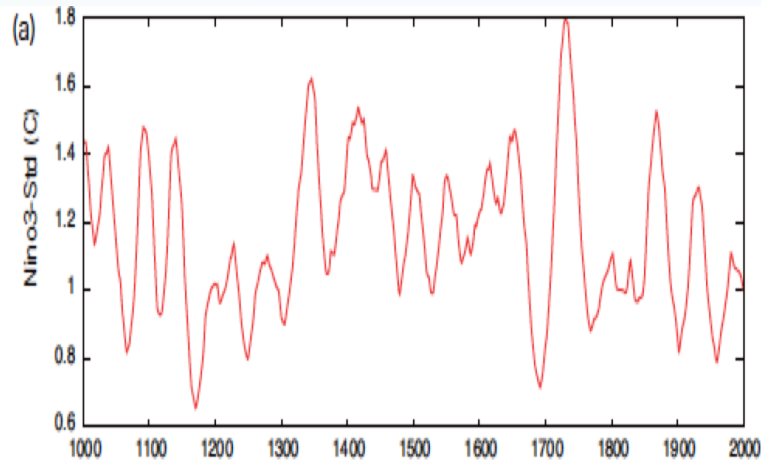
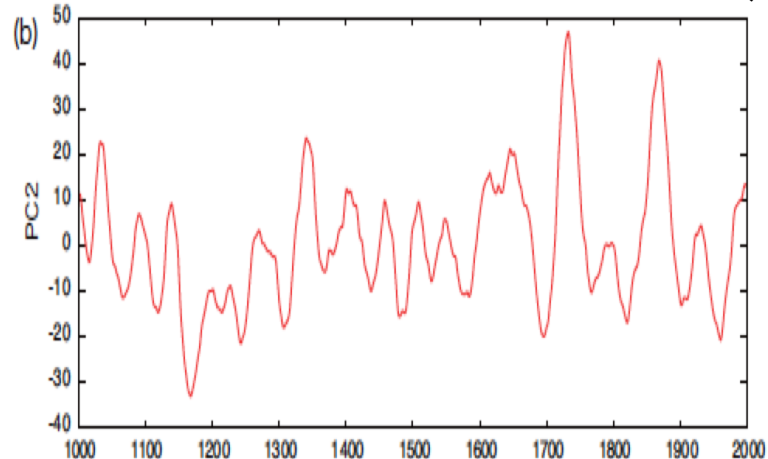- What is needed done further?

TPDV in Observations

SST difference between (1977−1999) and (1950−1976)
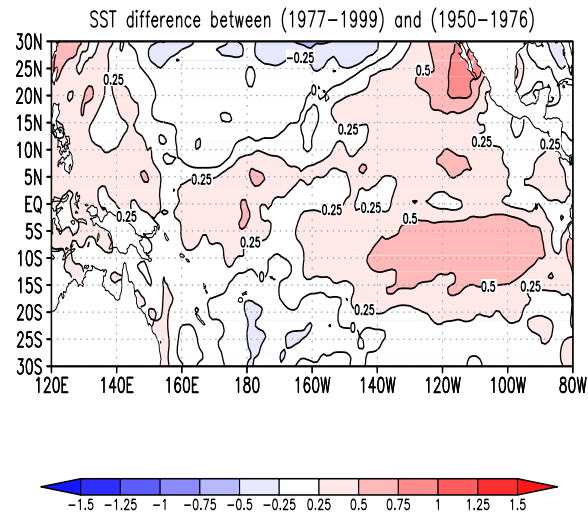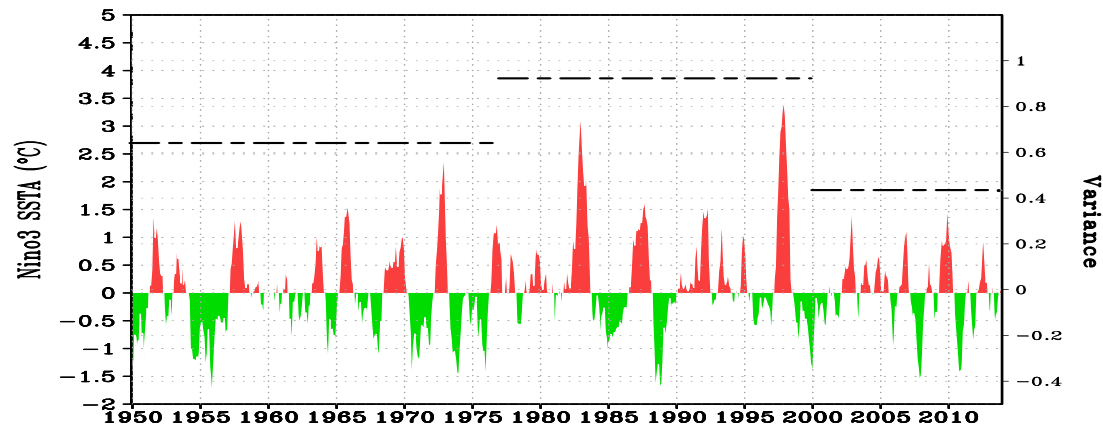
From Liang et al. (2012)

TPDV in Climate Models

Decadal Variation in the STD of Nino3 SST

Spatial Pattern of TPDV in **GFDL CM2.1**

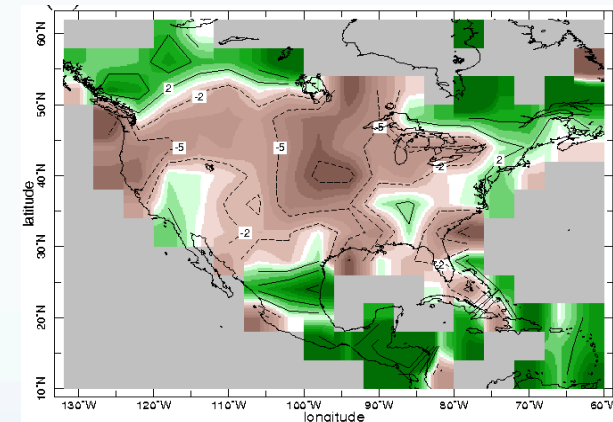Decadal Variation in the Mean State (TPDV)
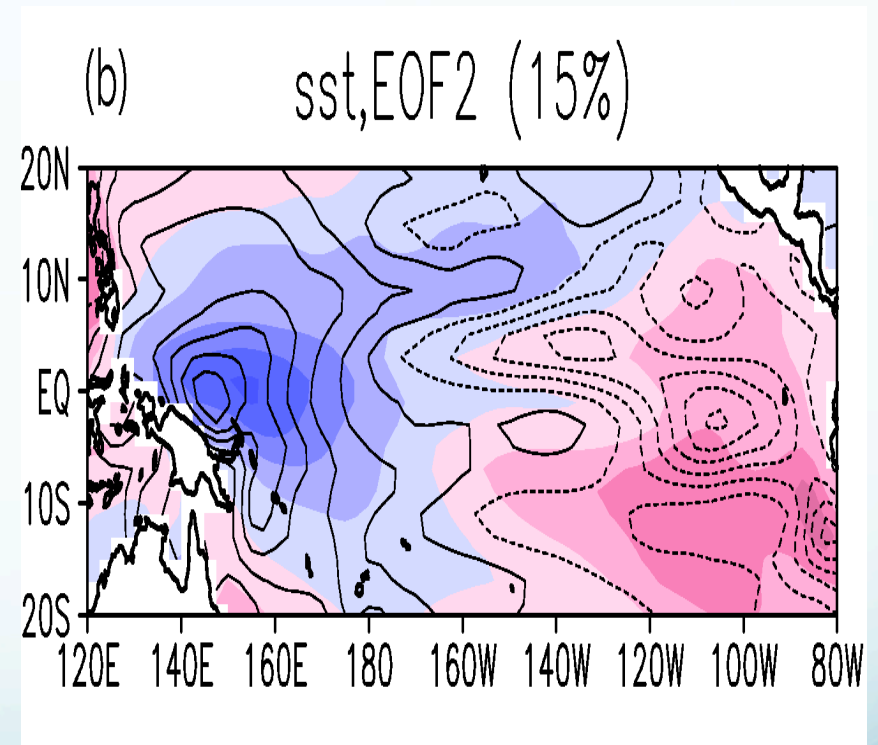
Ogata et al. 2013

TPDV is a leading cause of lasting droughts over the continental U.S.
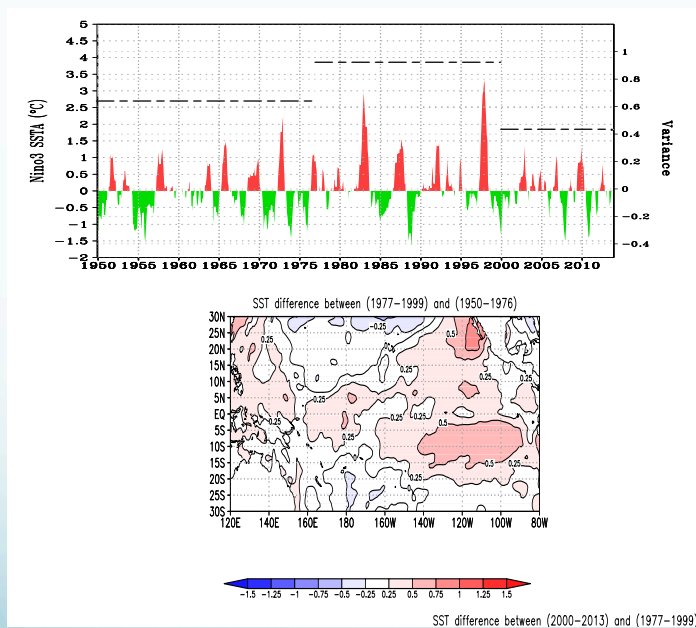
(Shubert et al. 2004, Seager et al. 2005, and others)

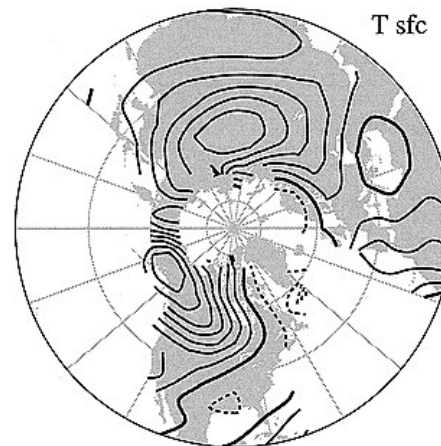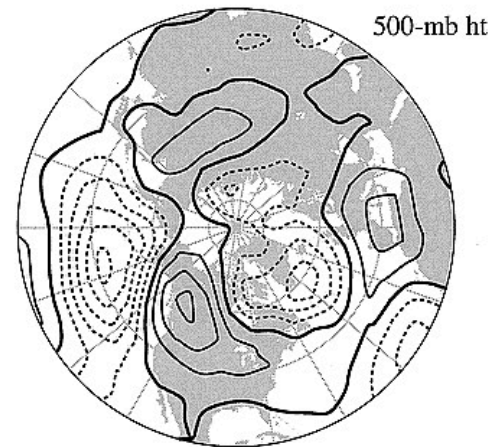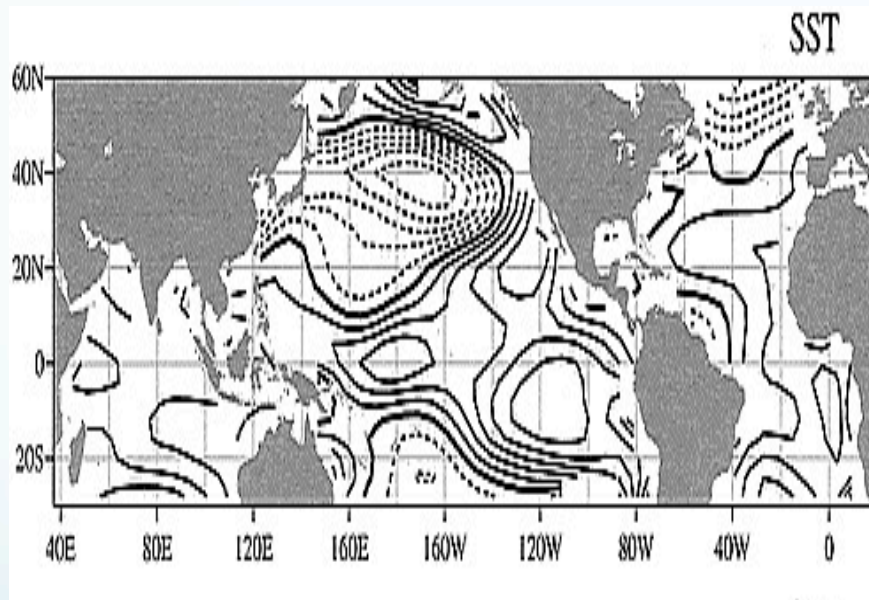Precipitation Anomaly (1932—1939)

Seager et al. (2007)

TPDV is the Epicenter of PDO and
Cause Climate Anomalies Worldwide Including Those Affecting
The Marine Ecosystem

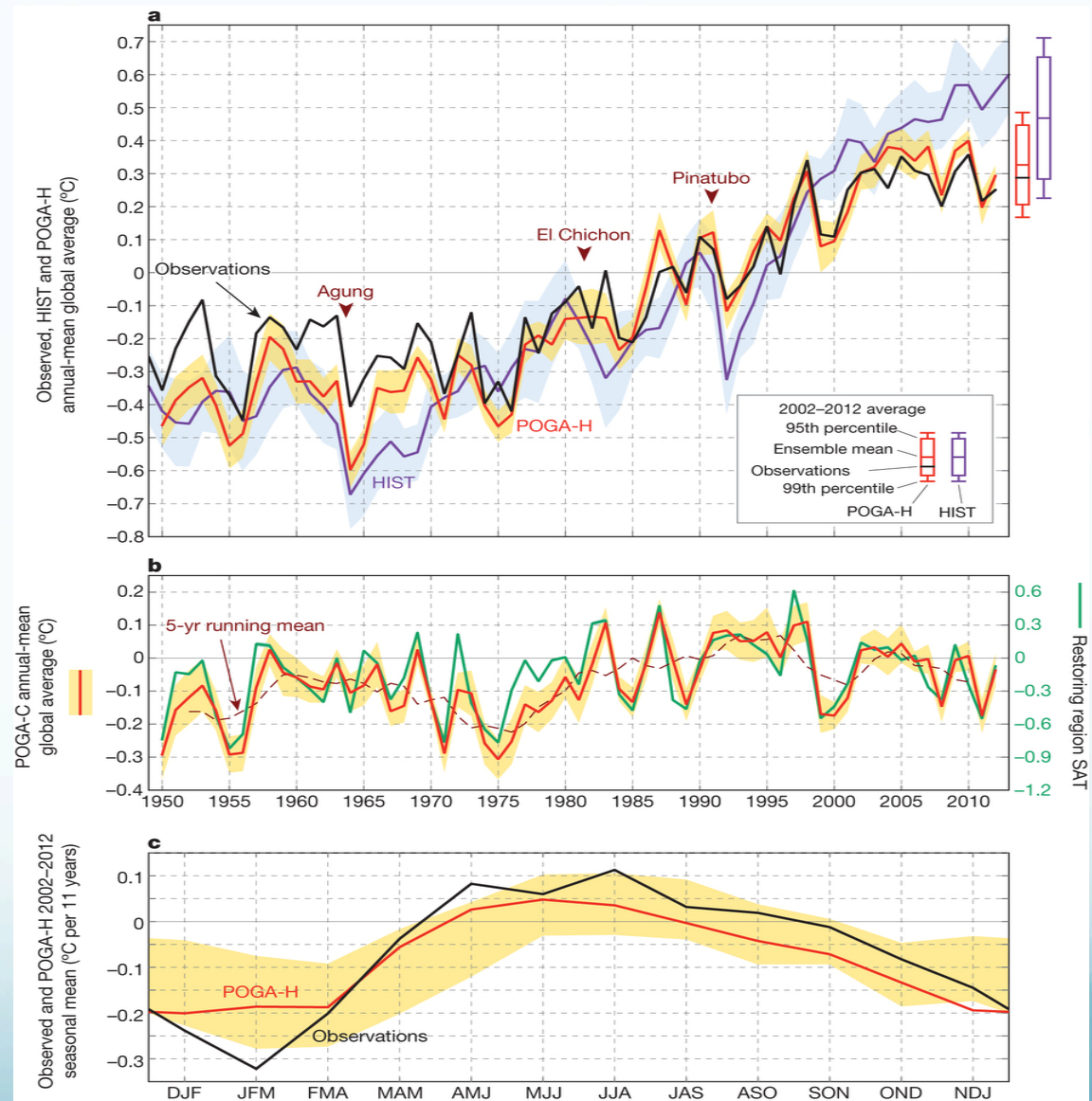Zhang et al. 1997, Mantua et al. 1997, Newman et al. 2003, 2015

TPDV Causes The Hiatus in Global Warming!

S.-P. Xie

**Kosaka and Xie 2013:
Hiatus happened
because eastern tropical
Pacific started to cool!**

What Causes TPDV?

① Transmission of the decadal variability in the extra-tropics to the tropics through atmospheric or ocean pathways (Deser et al. 1996, Weaver 1999, Kleeman et al. 1999, Barnett et al. 1999)

② Tropical—extratropical interaction (Gu and Philander 1997, Wu et al. 2003)

③ Tropical ocean-atmosphere interaction on the decadal time-scale (Knutson and Manabe 1998, Chang et al. 2001, Luo and Yamagata 2001)

④ Chaotic dynamics—a homoclinic/heteoclinic scenario of chaos (Timmerman and Jin 2002)

⑤ Stochastic forcing from the atmosphere upon the tropical Pacific (Clement et al. 2011, Okumura 2013).

⑥ Nonlinear Interaction between the time-mean effect of El Nino-Southern Oscillation and its decadal background state (Roger et al. 2004, Schopf and Burgman 2006, Sun and Yu 2008, Liang et al. 2012, Ogata et al. 2013, Sun et al. 2014, Hua et al. 2015)

Elements in
the Nonlinear Interaction Hypothesis

1) Decadal warming in the eastern tropical Pacific (such as the anomalous warm SST spanning from the mid of 1970s to the end of last century) is a consequence of the time-mean effect (or rectification effect) of anomalously high ENSO activity during this period.

2) Conversely, decadal cooling in the eastern tropical Pacific (such as the most recent cooling that has been linked to the hiatus in global mean temperature) is a consequence of the relative quiescence of ENSO activity.

3) The time-mean effect of anomalously high ENSO activity has such a spatial pattern and magnitude that it result in a significant reduction in the temperature difference between the warmpool and the subsurface thermocline (Tw-Tc)—the thermal force that drives this anomalous ENSO activity in the first place. (In other words, the anomalously higher/low activity of ENSO is self-destructive)

4) During the relative quiescent period of the ENSO activity, the meridional differential heating and the background meridional circulation that have always worked in the background retake preeminence and build up the thermal forcing (tw-Tc) that drives ENSO activity, setting the stage for the onset of another epoch of higher level of ENSO activity.

5) Nonlinear interaction between the time-mean effect of ENSO and its decadal background state generates continuous tropical Pacific Decadal Variability—alternating decades with relatively warmer and colder eastern Pacific. The initial warming to the central Pacific from the time-mean effect of ENSO may serve as a positive feedback that enables the system to overshoot its equilibrium.

Questions

to be answered to test the hypothesis

- Is there a significant time-mean effect from ENSO?

- Does the time-mean effect match the observed spatial pattern of decadal change?

- Does the time-mean effect have such a spatial pattern that enables a modulation of ENSO activity?

Inferring ENSO time-mean effect from its asymmetry

Observation
(a) Warm Phase

(b) Cold Phase

(c) Warm Phase + Cold Phase
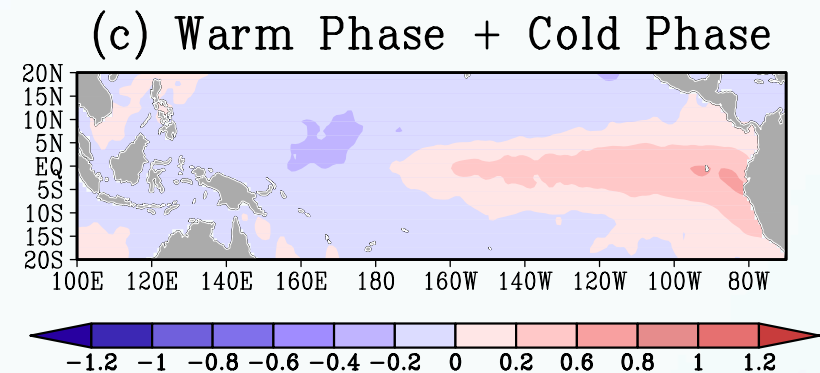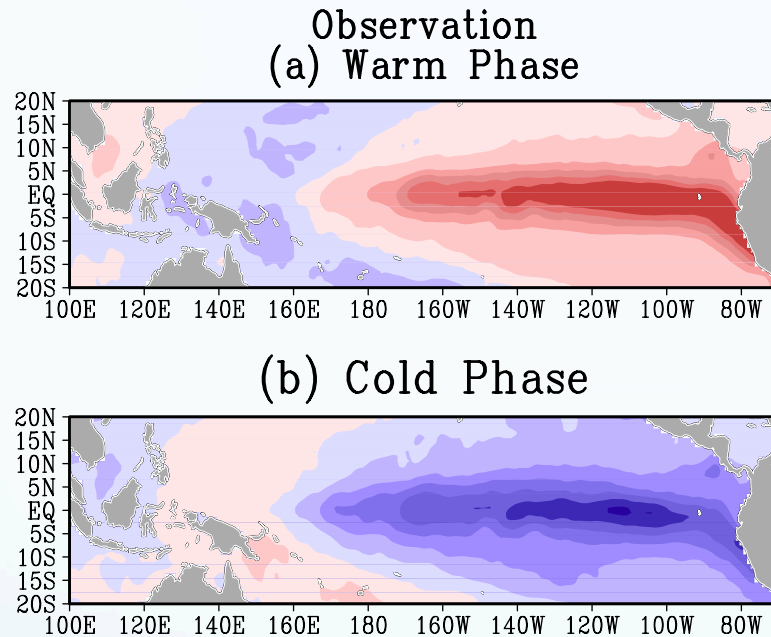
1. ENSO asymmetry suggests a time-mean effect, but does not guarantee one
2. The residual (sum of the anomalies of the two phases of ENSO) has its maximum on the equator, while the observed decadal warming does not.

Our Methodologies

to determine

The Time-Mean Effect of ENSO

- Compare *the equilibrium state* of the coupled tropical ocean-atmosphere system with the time-mean state of the system, though the use of a box model whose unstable equilibrium can be analytically obtained (Liang et al. 2012)

- **Force an Ocean GCM using surface forcing with and without ENSO fluctuations (Sun et al. 2014, Hua et al. 2015)**

- Perturbation Experiments with coupled GCMs with and without equatorial coupling between surface winds and SST gradients (Sun and Zhang 2006, Yu and Sun 2009)

Forced Ocean GCM Experiments
with and without ENSO in the Surface Forcing

A   B

Atmosphere

Ocean

T_b T_b
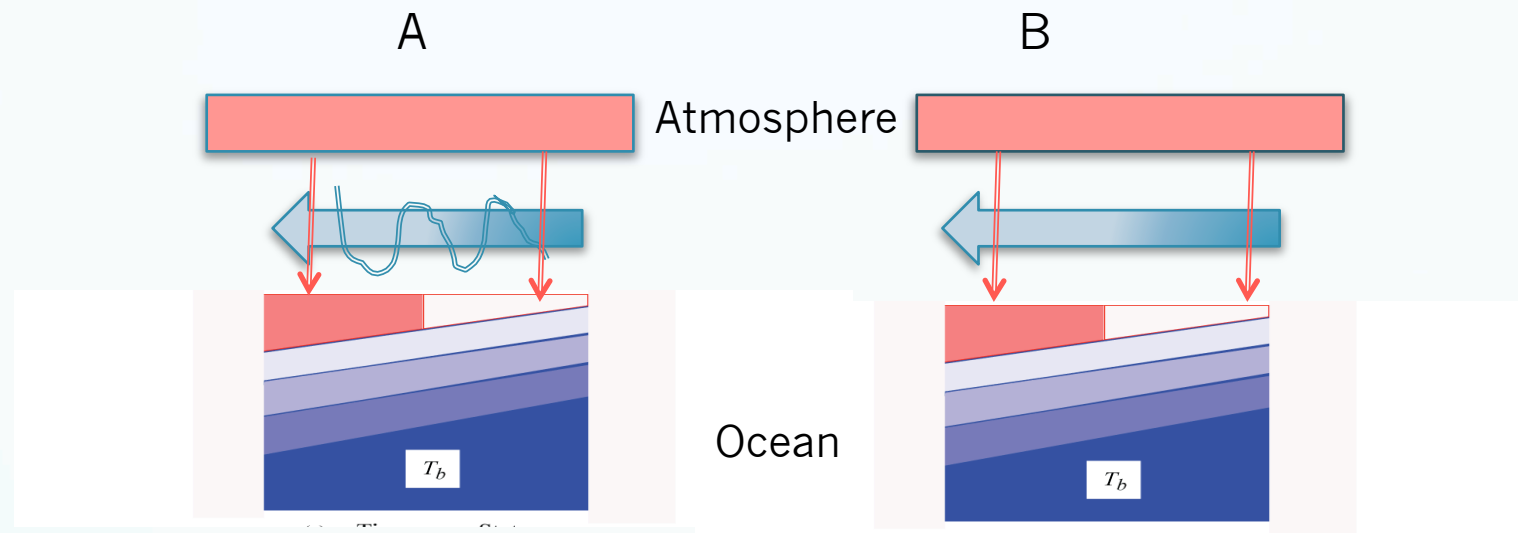
- The long-term mean winds are identical for A and B, but A has interannual variations and B does not.

- The thermal BCs for A and B are identical-- both are restored to a prescribed potential SST

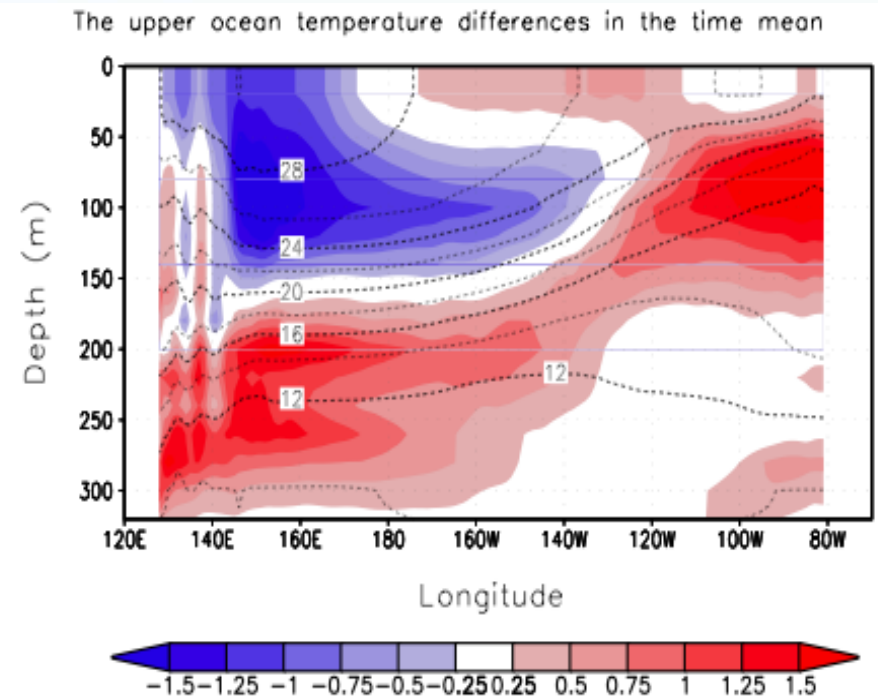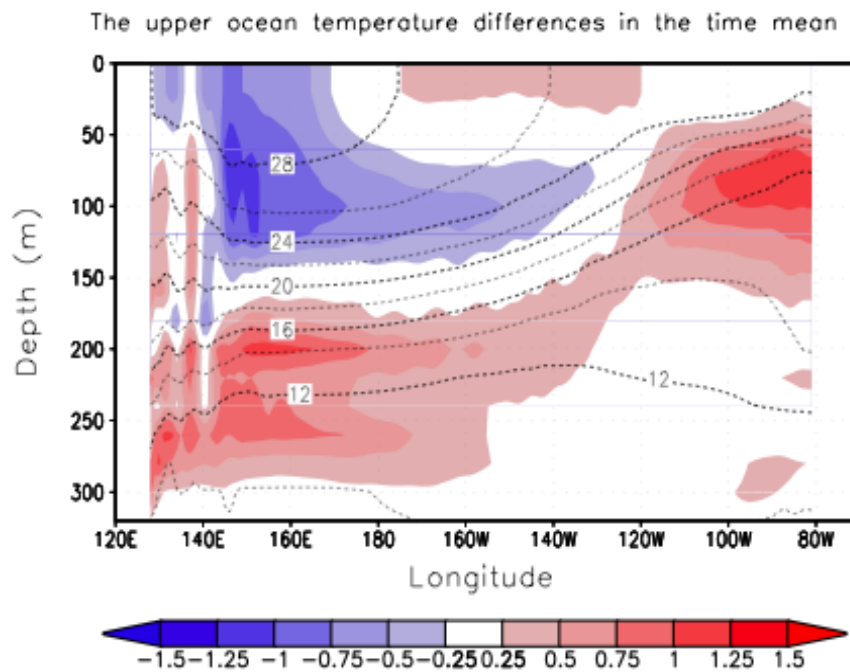# Time-Mean SST Difference
Between Experiments with/without ENSO

Time (year)
62yrs (1950−2011) time mean results (fluctuating wind minus fixed wind)
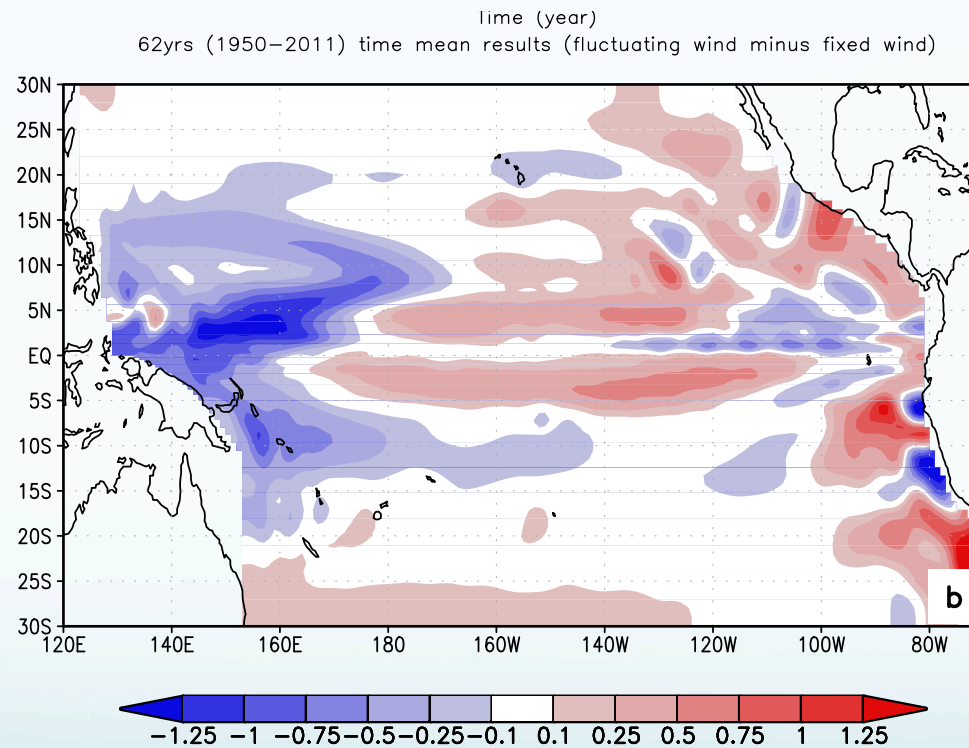
Time-mean Upper Ocean Tempt. Difference Between Experiments with/without ENSO

Time mean (1950−2011) upper ocean temperature differences
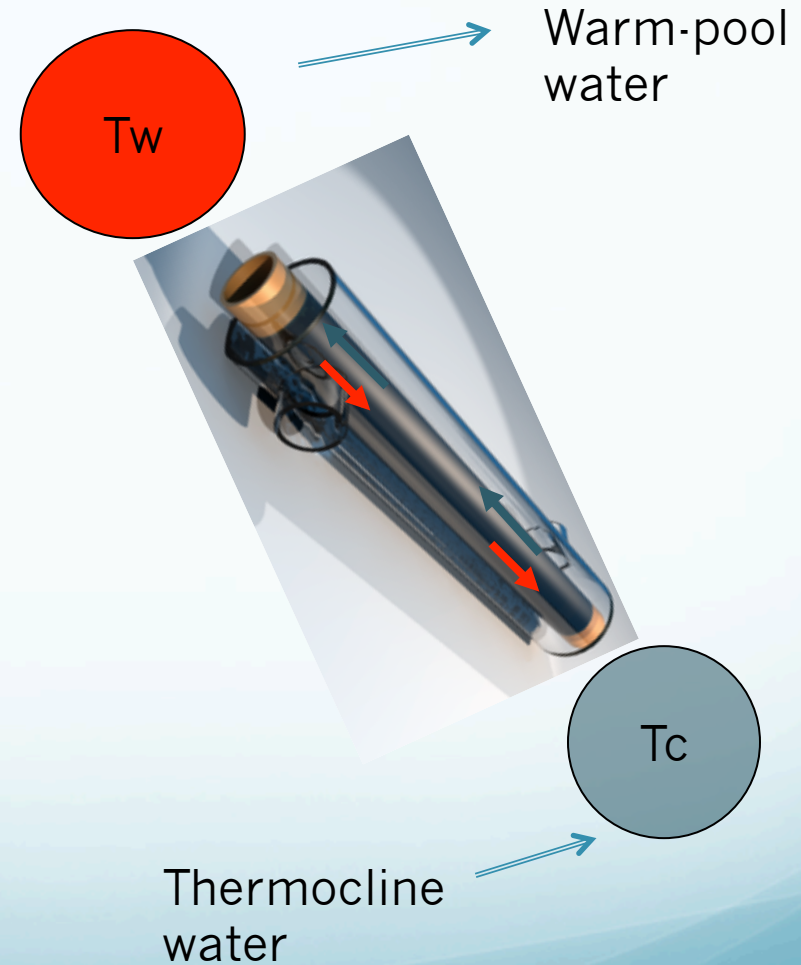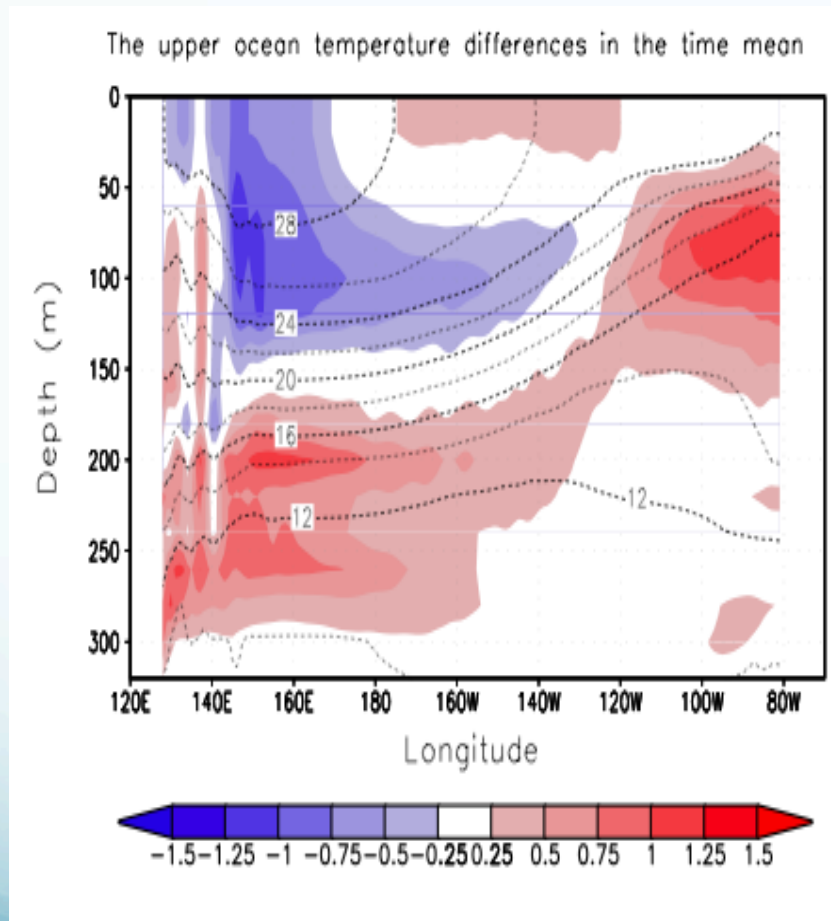
fluctuating wind runs − fixed wind runs
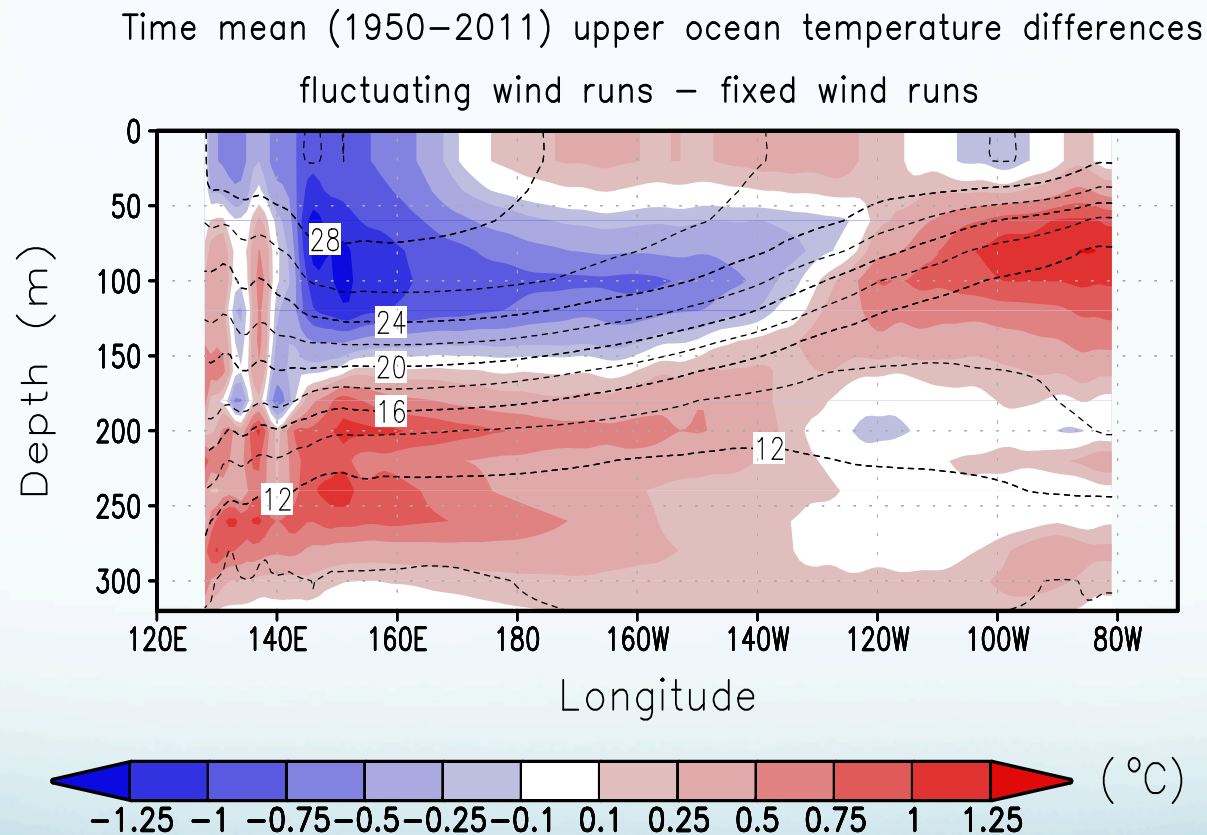
The rectified effect of ENSO in the Upper Ocean T: Sensitivity to the variance of ENSO

$$\tau'$$

$$1.5\tau'$$

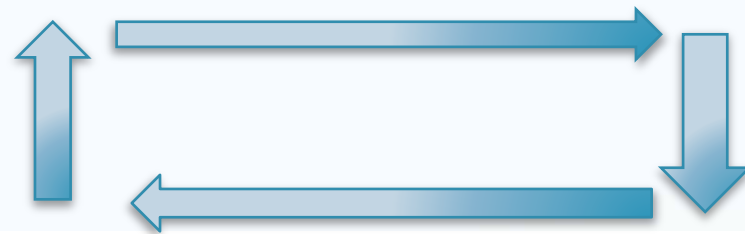The upper ocean temperature differences in the time mean

A Conceptual Picture for the Time-Mean Effect of ENSO: A Heat Mixer

The upper ocean temperature differences in the time mean
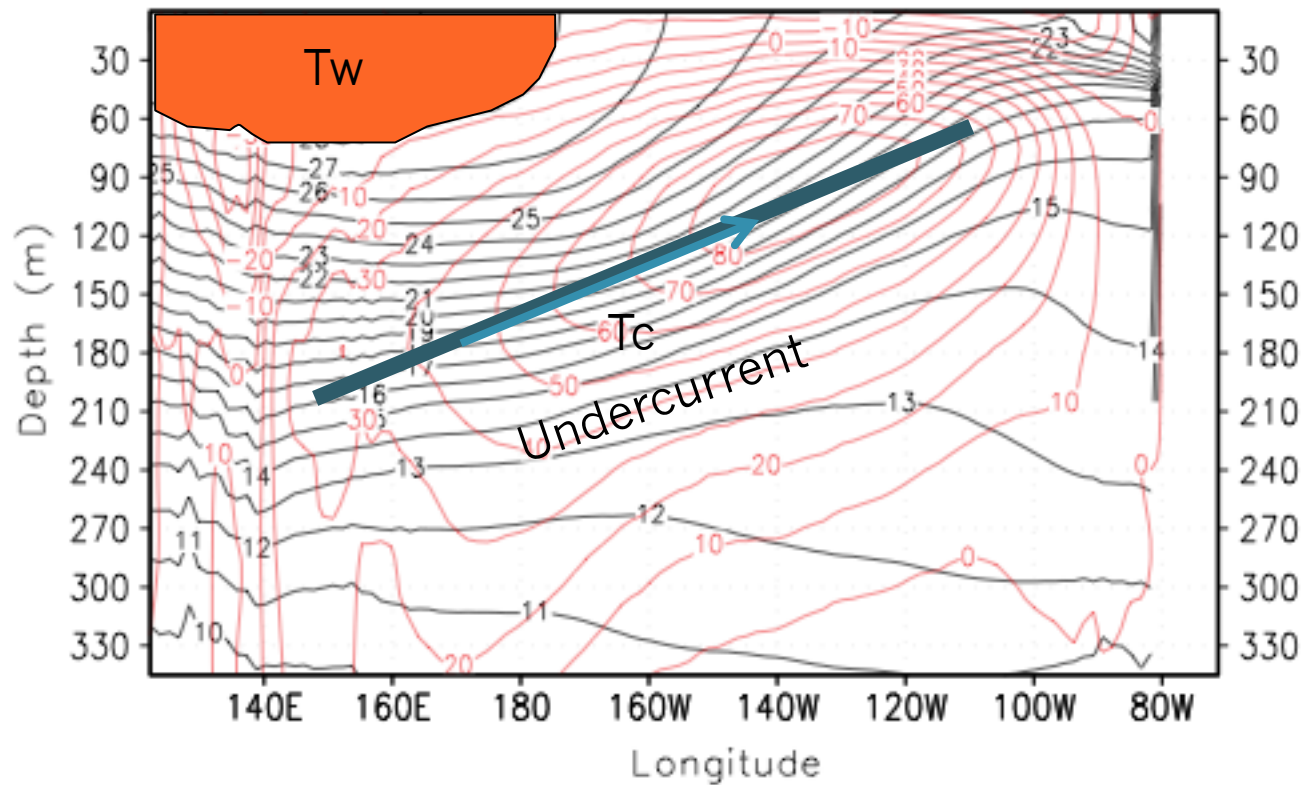
Warm-pool water

Tw

Tc

Thermocline water

# Recall That Tw-Tc Drives ENSO

Atmosphere

Walker Circulation

Ocean

Implications of the time-mean effect of ENSO events:

The fact that ENSO events collectively destroy the thermal gradient (i.e. Tw-Tc) that supports their existence in the first place implies that an elevated ENSO activity is **self-destructive**. A subdued period of activity is thus ensured to follow from an elevated period of activity.

New Question:

How does the system to **recover** from the stabilization of the time-mean effect of ENSO events?
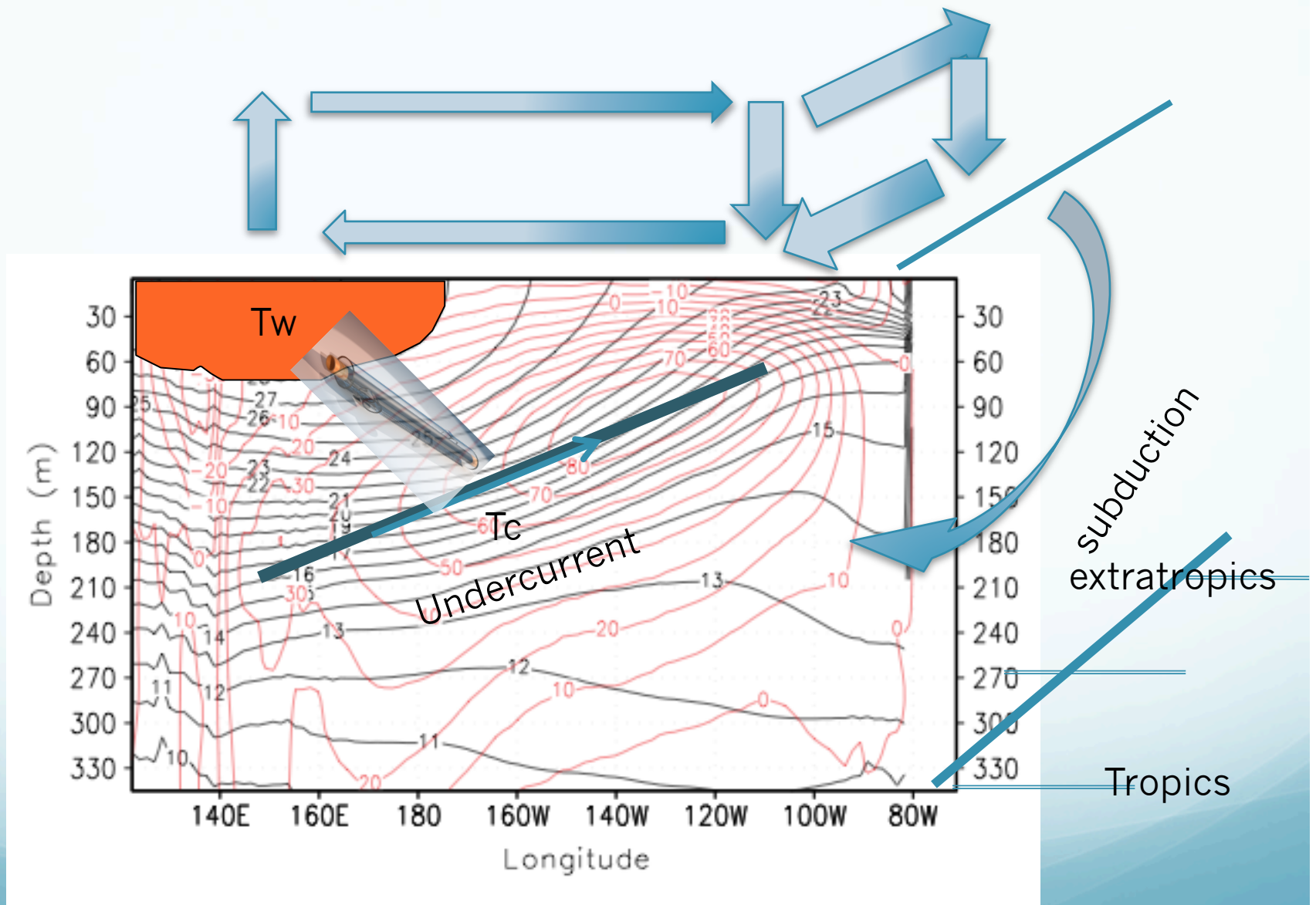
The Opposing Forces:
The Meridional Differential Heating and the Meridional Cell
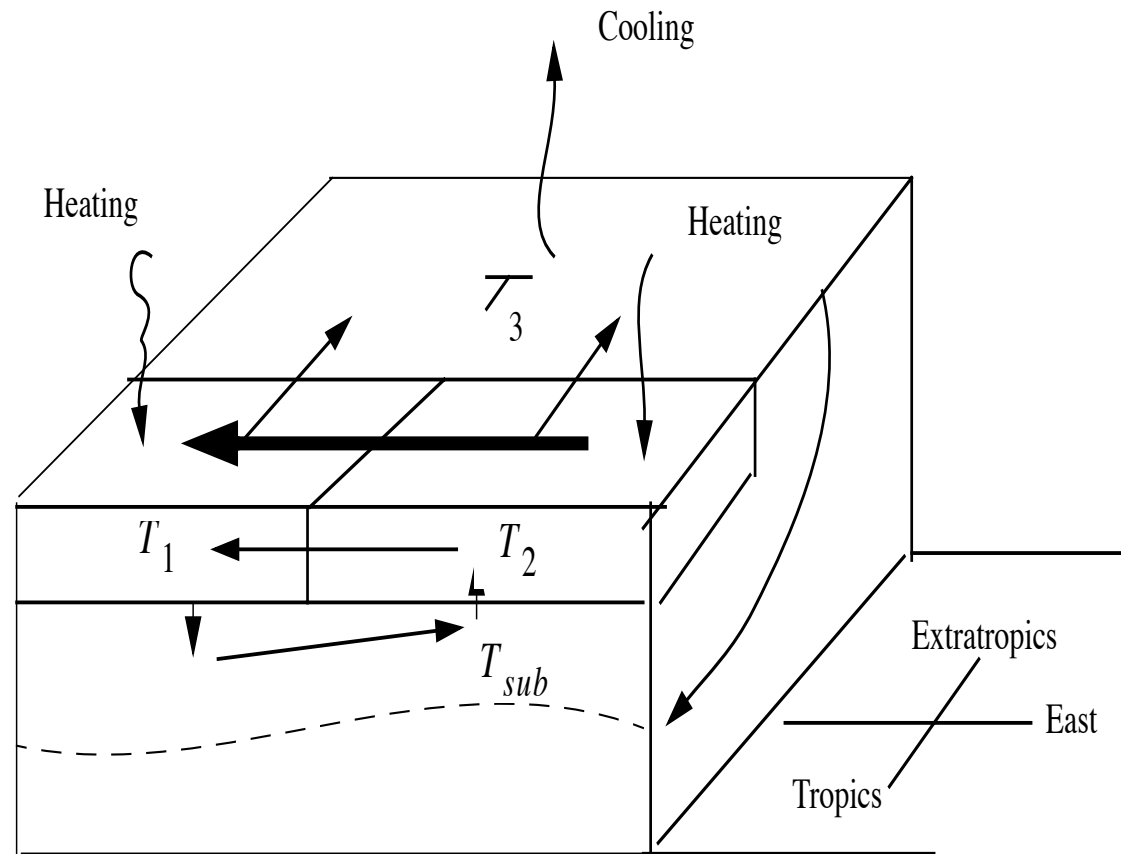
The maintenance of the long-term mean thermal gradients

A Nonlinear Mechanism For
TPDV and Decadal Modulation of ENSO Activity